# Chapter 9: Stability of monolithic breakwaters

ct5308 Breakwaters and Closure Dams

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Delft University of Technology

# important aspects of caisson walls

- Quasi static load
- Impact forces

- sliding
- turning

- placing on a mound



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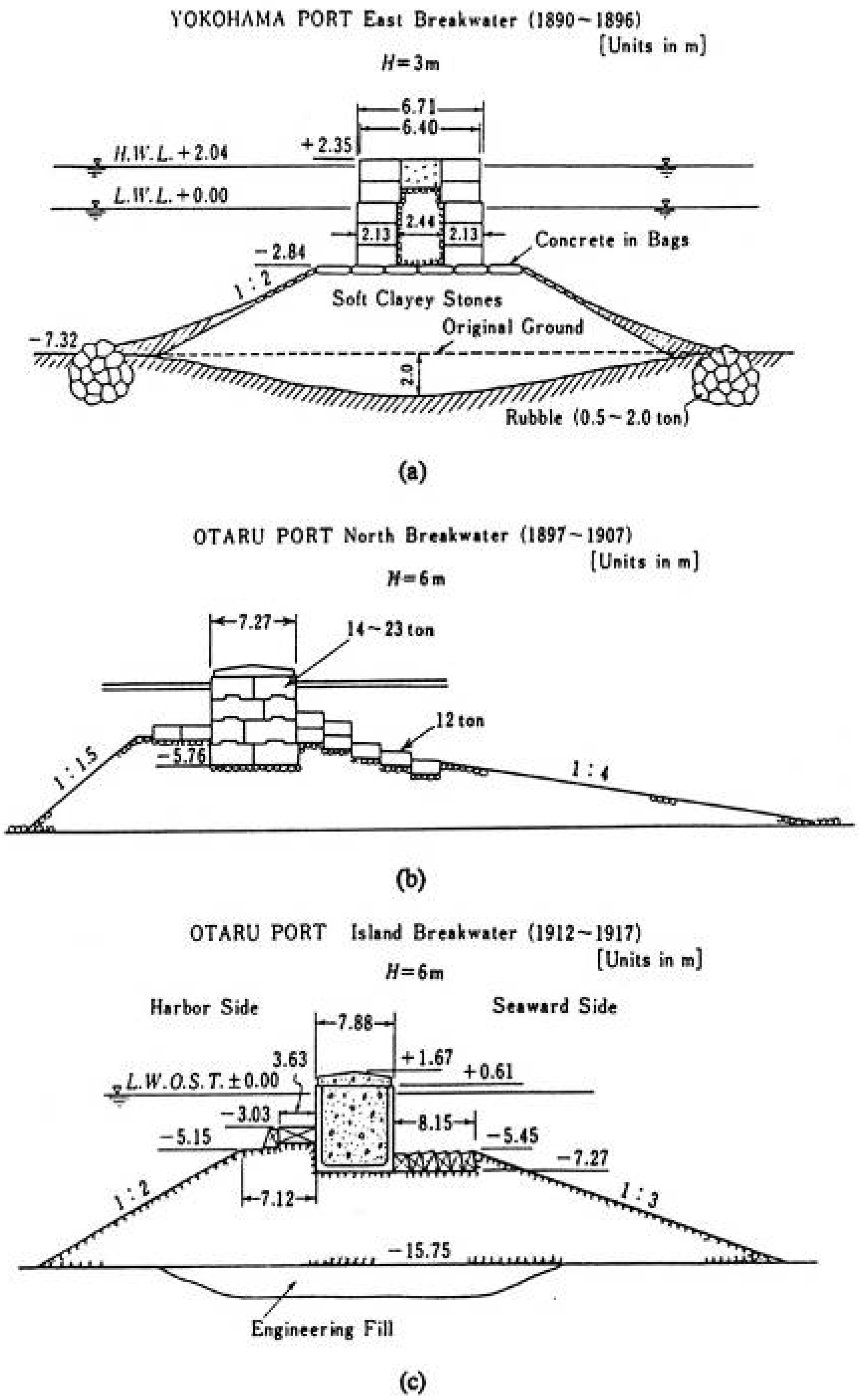
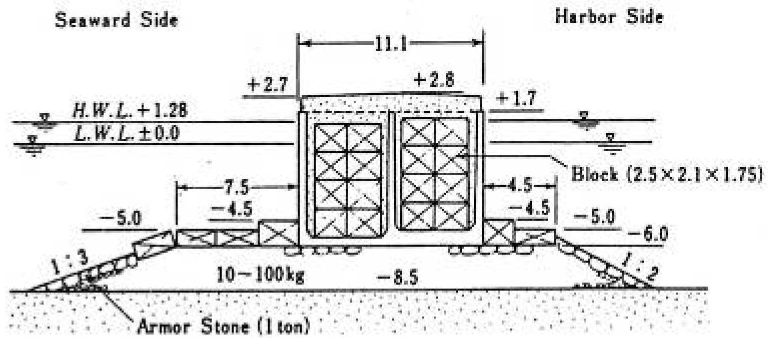



# historical development of breakwater in Japan

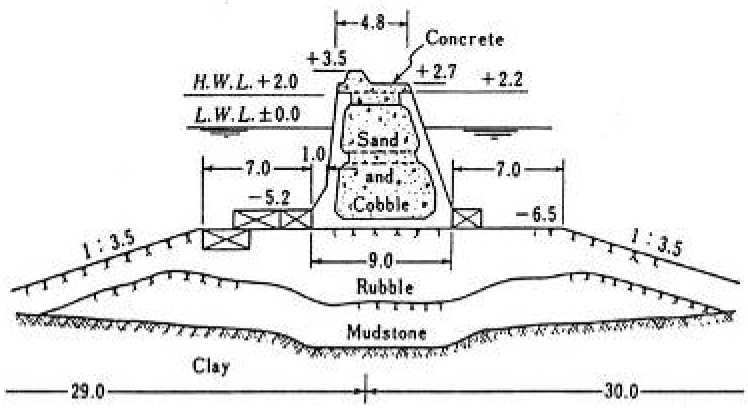
# historical development of breakwater in Japan (2)

ONAHAMA PORT First Breakwater (1929～1938)
[Units in m]
$H_{max}$=8.5m



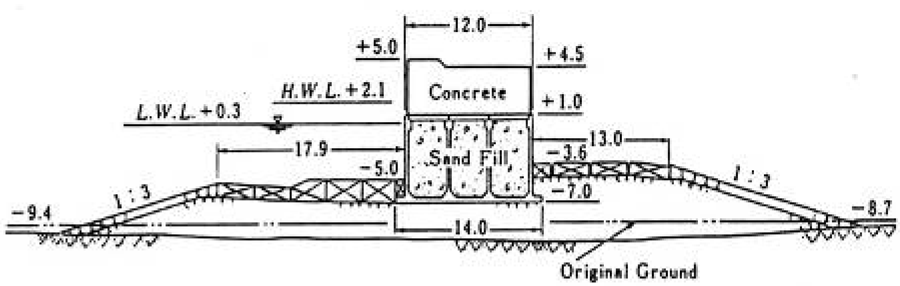

(d)

YOKOHAMA PORT Outer Breakwater (1928～1943)
[Units in m]
H=3m

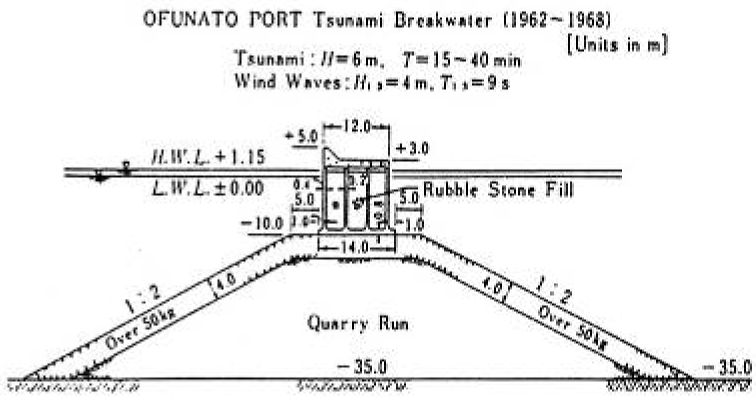



(e)

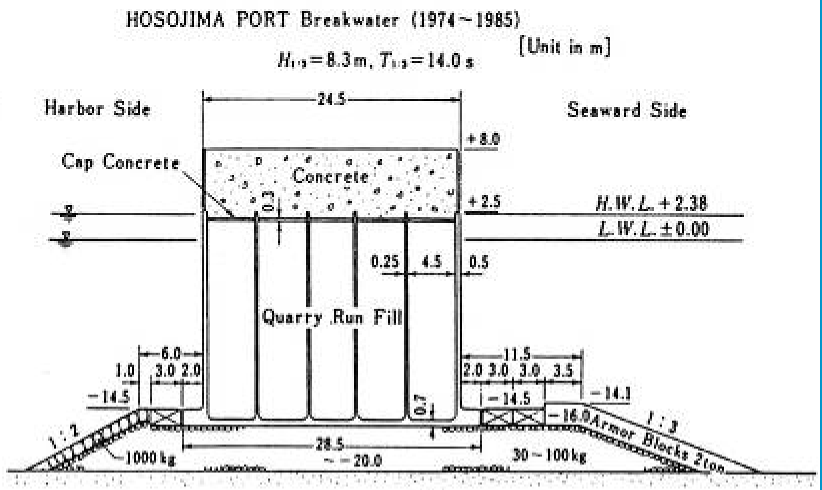
WAKAYAMA North Harbor-West Breakwater (1957～1960)
[Units in m]
$H_{1/3}$=6m



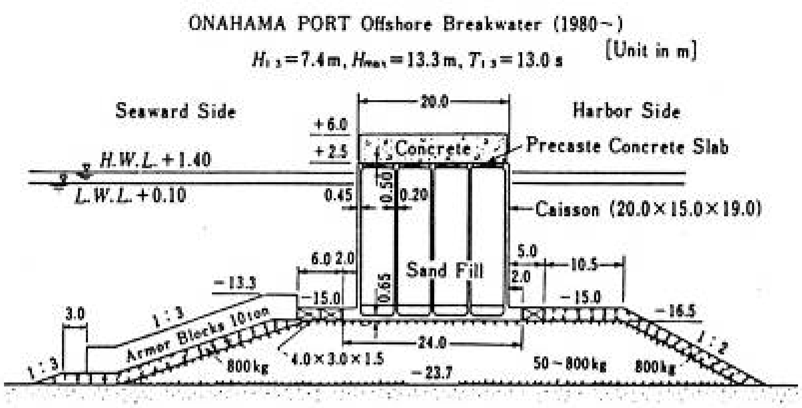

(f)




(g)




(h)




(i)

# historical development of breakwater in Japan (3)



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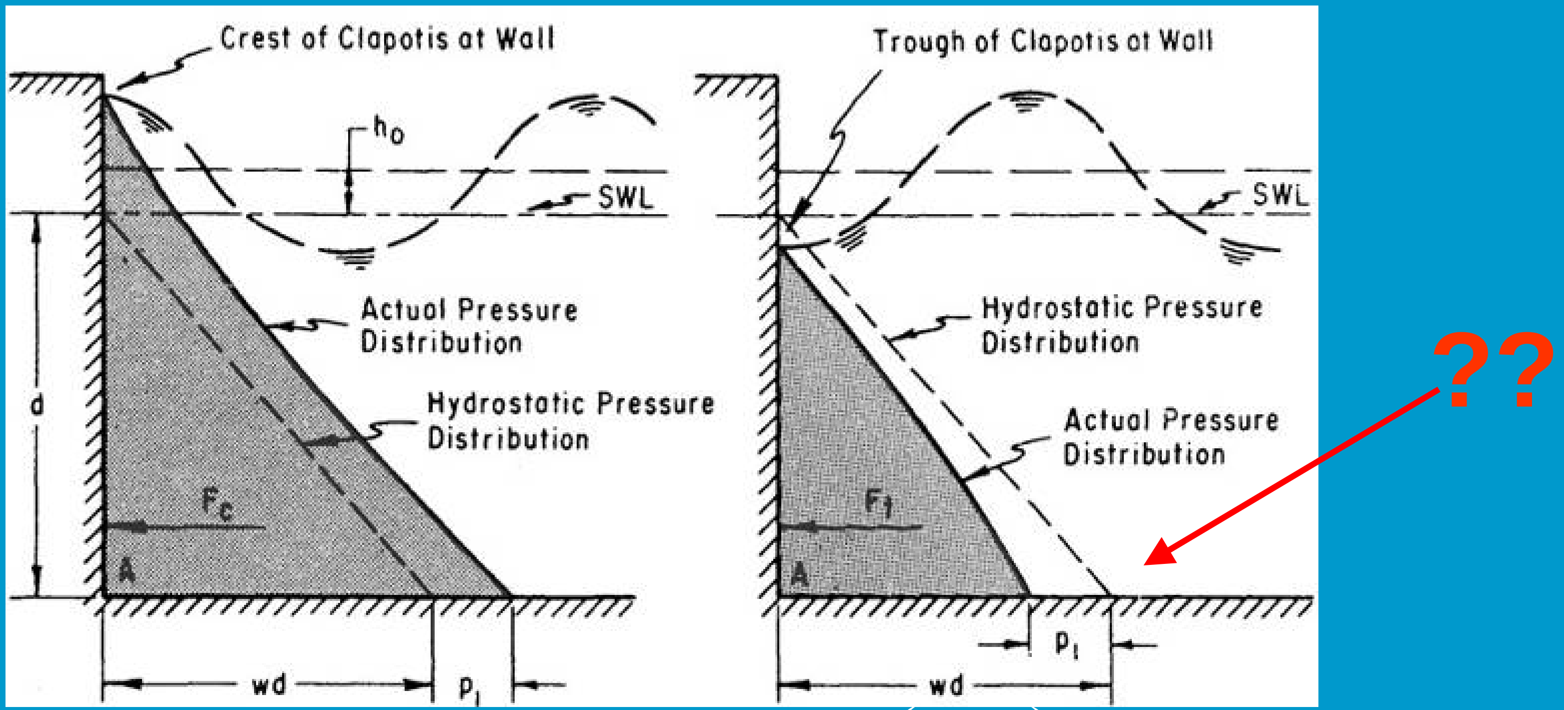
# schematic pressure distribution for non-breaking waves




$$wd = \rho g h \qquad p_1 = \left(\frac{1+r}{2}\right)\frac{\rho g H_i}{\cosh\left(2\pi h / L\right)}$$



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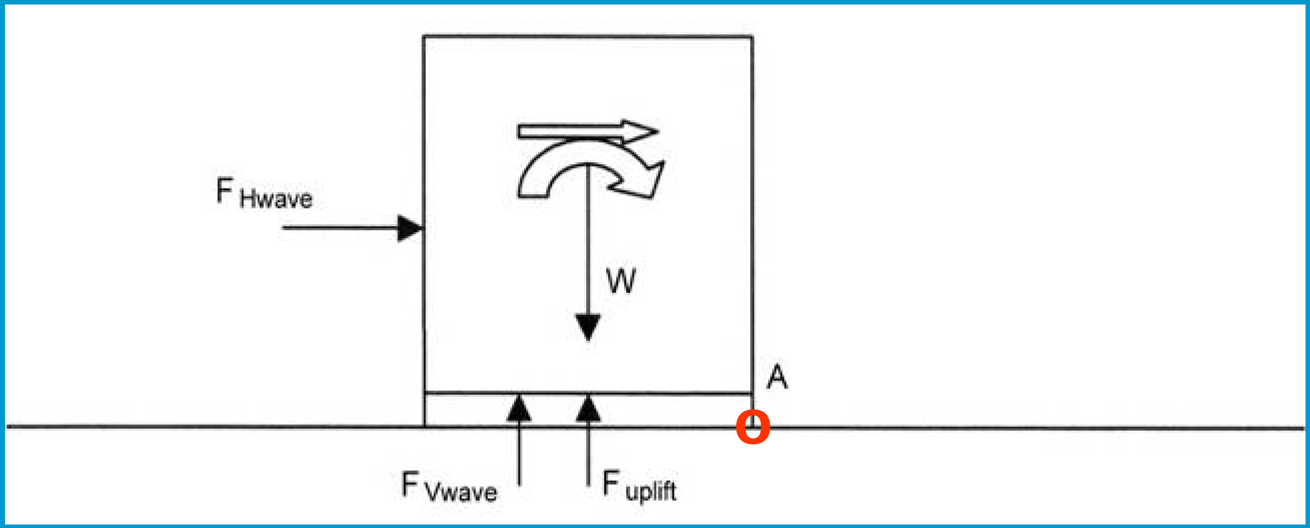
# load and equilibrium diagram



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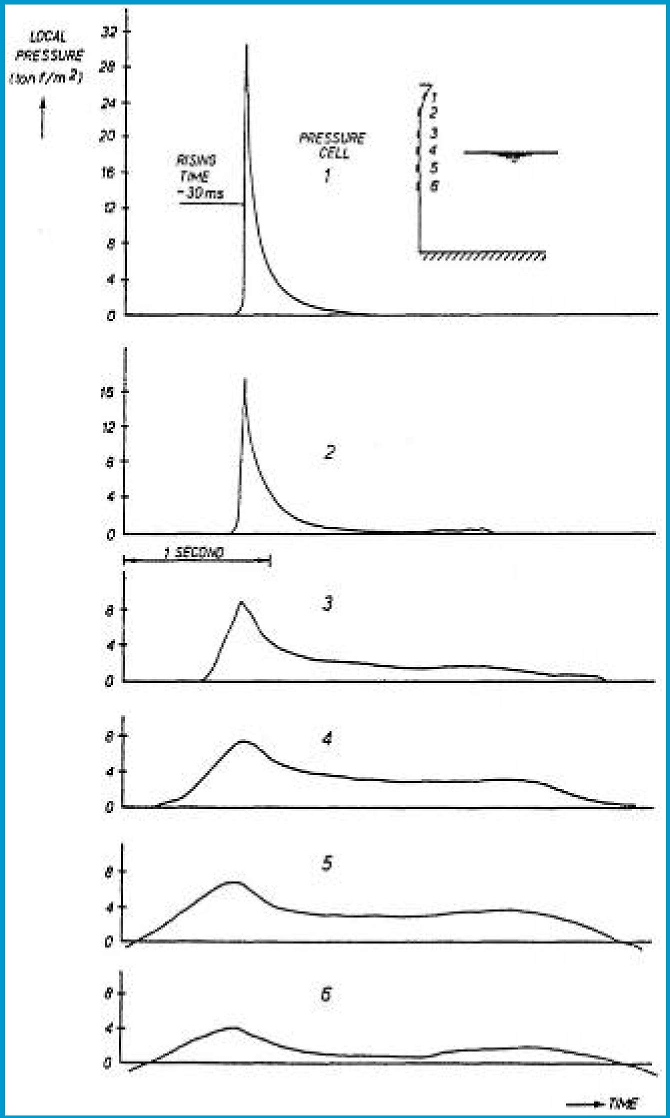


# example of a pressure record



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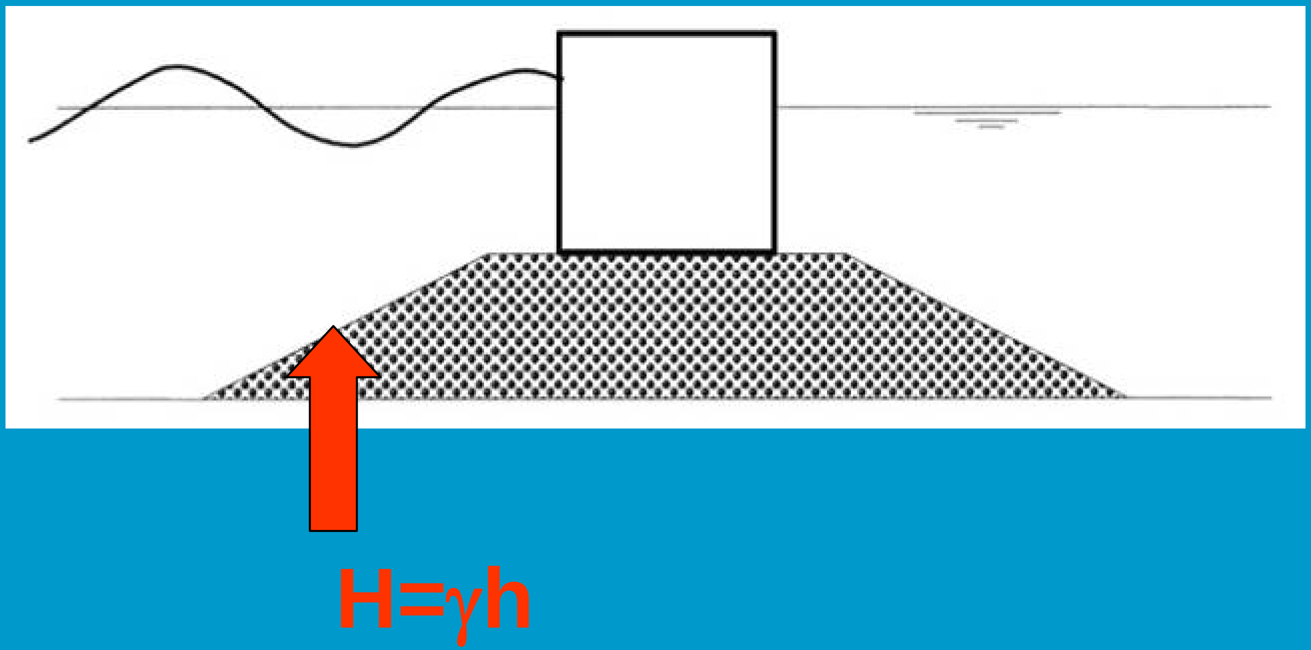
# changes to incoming wave front induced by high mound breakwater



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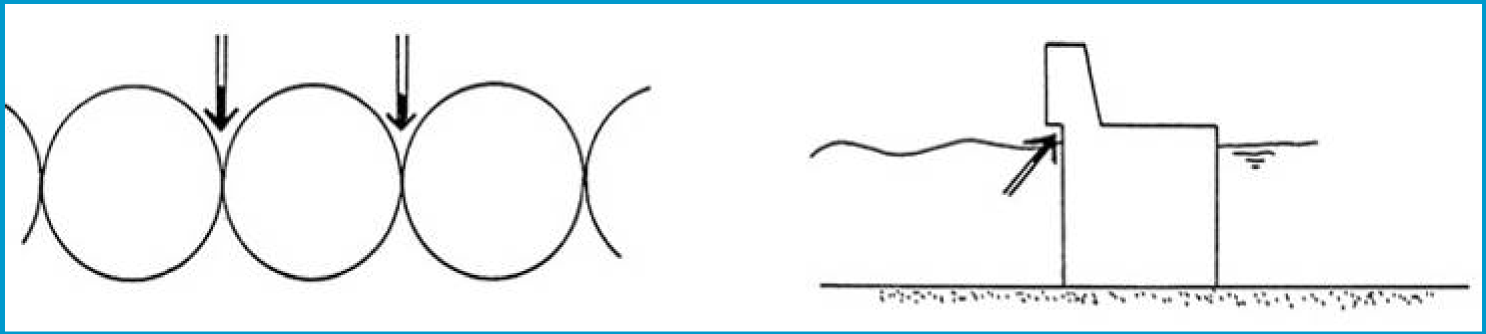
# Risk of local impact forces





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# Brighton Marina, UK



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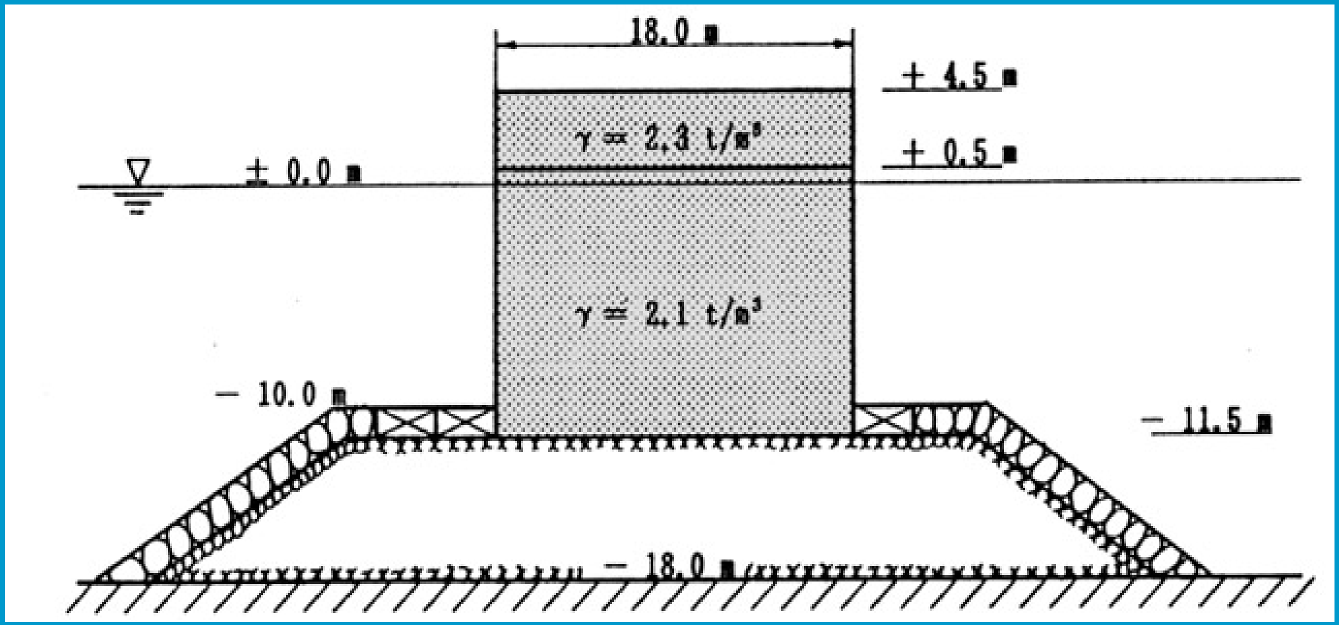
# Parapet damage

Damage due to typhoon Tokage (Oct 2004) Muroto Kochi, Japan

# Sketch of upright breakwater for stability analysis



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# wave pressure distribution

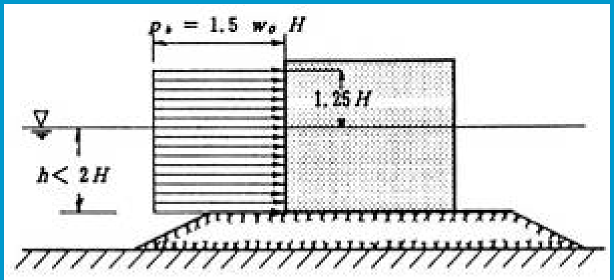
$$p_1 = \left(p_2 + w_0 h\right)\frac{H + \delta_0}{h + H + \delta_0}$$

$$p_2 = \frac{w_0 H}{\cosh kh}$$

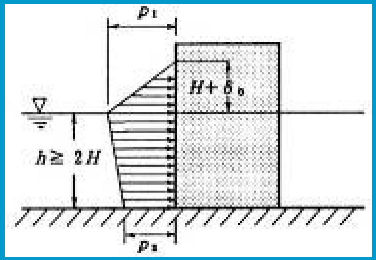
$$\delta_0 = \left(\pi H^2 / L\right)\coth kh$$

$p = 1.5\ w_0 H$

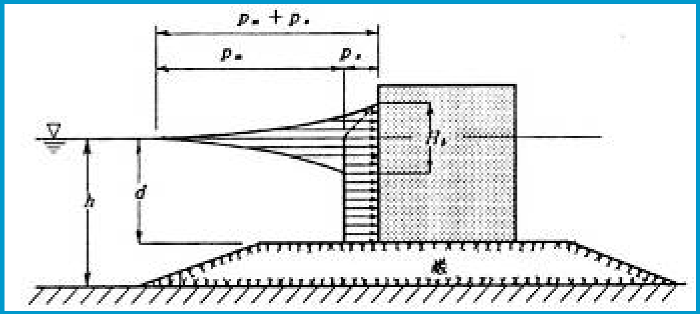
Hiroi




Sainflou




Minikin



# Design wave for Goda's method

- Wave height
  complicated method (formula of a magician)
- Wave period
  $T_{max} = T_{1/3}$
- Angle of incidence $\beta$
  Assume an approach of 15 degrees to the normal



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# Design wave height according to Goda

$$H_{\max} = \begin{cases} 1.8 H_{1/3} & : h/L_0 \geq 0.2 \\ \min\left\{\left(\beta_0^* H_0' + \beta_1^* h\right), \beta_{\max}^* H_0', 1.8 H_{1/3}\right\} & : h/L_0 < 0.2 \end{cases}$$

$$H_{1/3} = \begin{cases} K_s H_0' & : h/L_0 \geq 0.2 \\ \min\left\{\left(\beta_0 H_0' + \beta_1 h\right), \beta_{\max} H_0', K_s H_0'\right\} & : h/L_0 < 0.2 \end{cases}$$



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# Goda's coefficients

$$\beta_0 = 0.028\left(H_0'/L_0\right)^{-0.38}\exp\left(20\tan^{1.5}\theta\right)$$

$$\beta_1 = 0.52\exp\left(4.2\tan\theta\right)$$

$$\beta_{max} = \max\left\{0.92, 0.32\left(H_0'/L_0\right)^{-0.29}\exp\left(2.4\tan\theta\right)\right\}$$

---

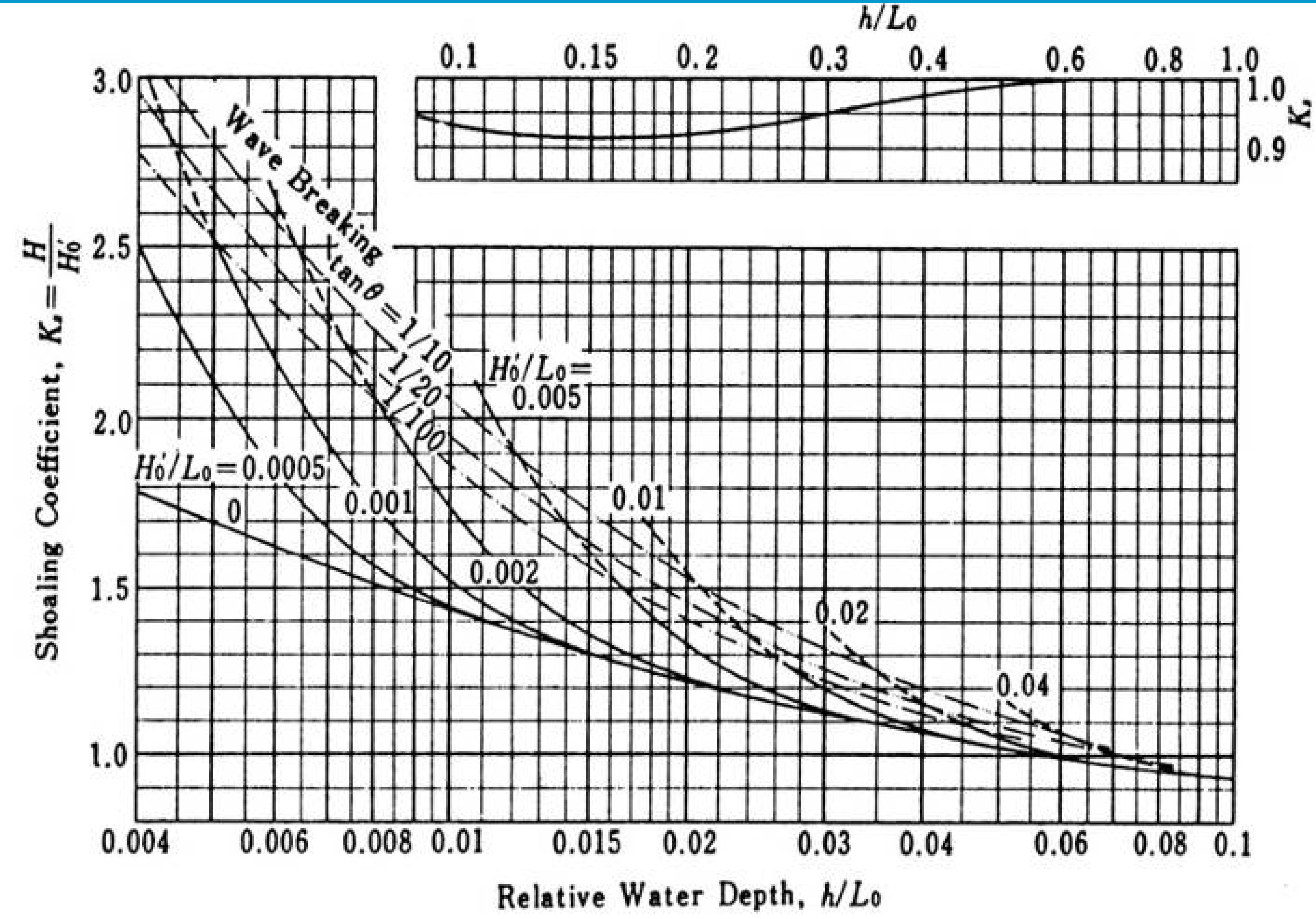
$$\beta_0^* = 0.052\left(H_0'/L_0\right)^{-0.38}\exp\left(20\tan^{1.5}\theta\right)$$

$$\beta_1^* = 0.63\exp\left(3.8\tan\theta\right)$$

$$\beta_{max}^* = \max\left\{1.65, 0.53\left(H_0'/L_0\right)^{-0.29}\exp\left(2.4\tan\theta\right)\right\}$$

θ is the inclination of the seabed

# Nonlinear shoaling coefficient



# surface elevation

rise of the water above the caisson:

$$\eta^* = 0.75\ (1+\cos\beta)\ H_{max}$$



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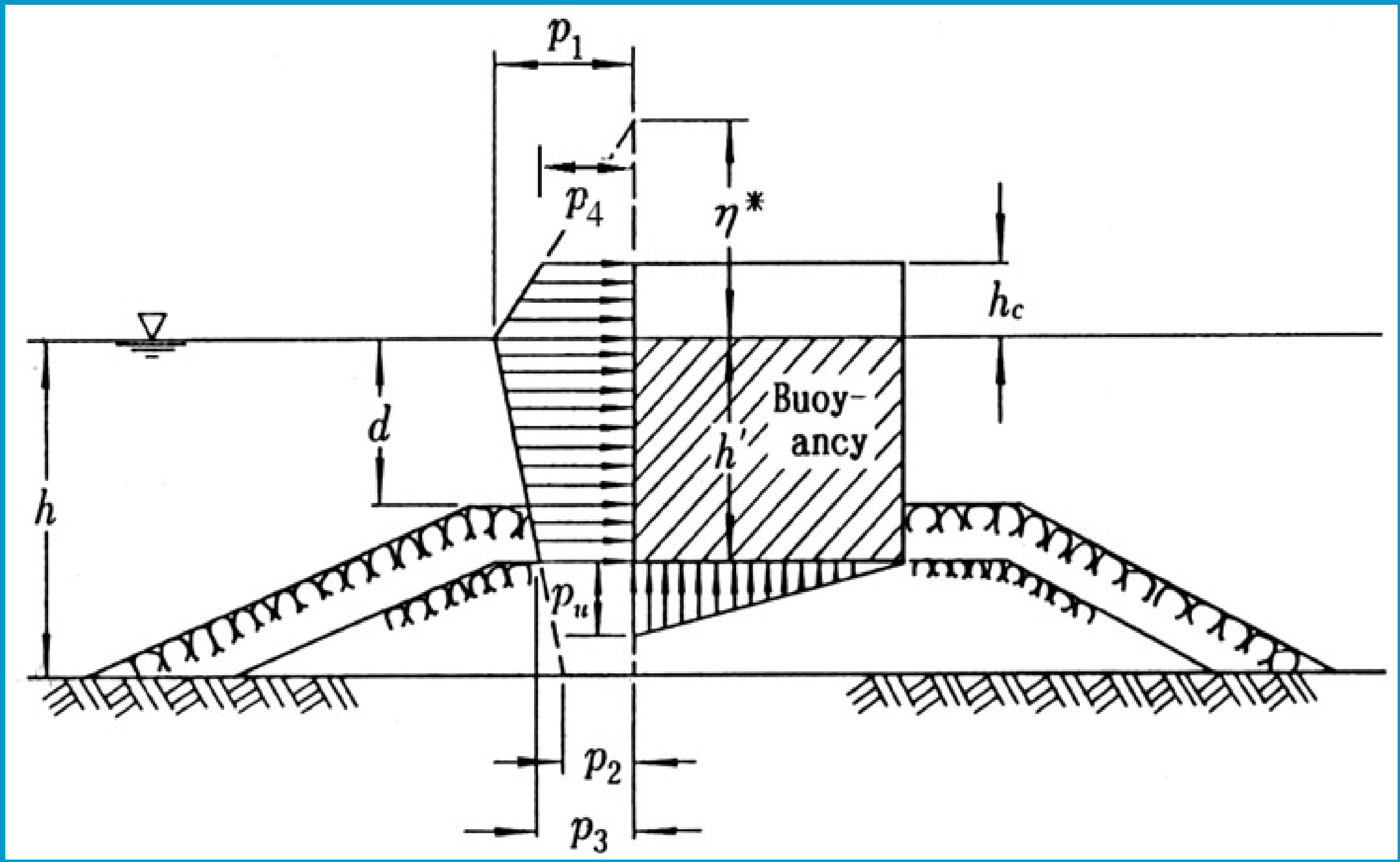
# wave pressure with Goda’s formula



# pressure values according to Goda

$$p_1 = 0.5(1+\cos\beta)(\alpha_1 + \alpha_2 + \cos^2\beta) w_0 H_{max}$$

$$p_2 = {p_1}/{\cosh kh}$$

$$p_3 = \alpha_3 p_1$$

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$$\alpha_1 = 0.6 + 0.5\left(\frac{2kh}{\sinh 2kh}\right)^2$$

$$\alpha_2 = \min\left\{\frac{h_b - d}{3h_b}\left(\frac{H_{max}}{d}\right)^2, \frac{2d}{H_{max}}\right\}$$

$$\alpha_3 = 1 - \left(\frac{h'}{h}\right)\left(1 - \frac{1}{\cosh kh}\right)$$

$h_b$ is waterdepth at 5 $H_{1/3}$ seaward from breakwater



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# uplift pressure

$$p_u = 0.5(1 + \cos\beta)\alpha_1 \alpha_3 w_0 H_{\max}$$



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# safety factors

| | | |
|---|---|---|
| against sliding | $\mu(W-U)/P$ | >1.2 |
| against overturning | $(Wt-M_U)/M_P$ | >1.2 |

| | |
|---|---|
| $M_P$ | moment of total wave pressure around the heel |
| $M_U$ | moment of total uplift pressure around the heel |
| $P$ | total thrust of wave pressure |
| $t$ | horizontal distance between centre of gravity and the heel |
| $U$ | total uplift pressure |
| $W$ | weight of the unit |
| $\mu$ | coefficient of friction (order of 0.6) |



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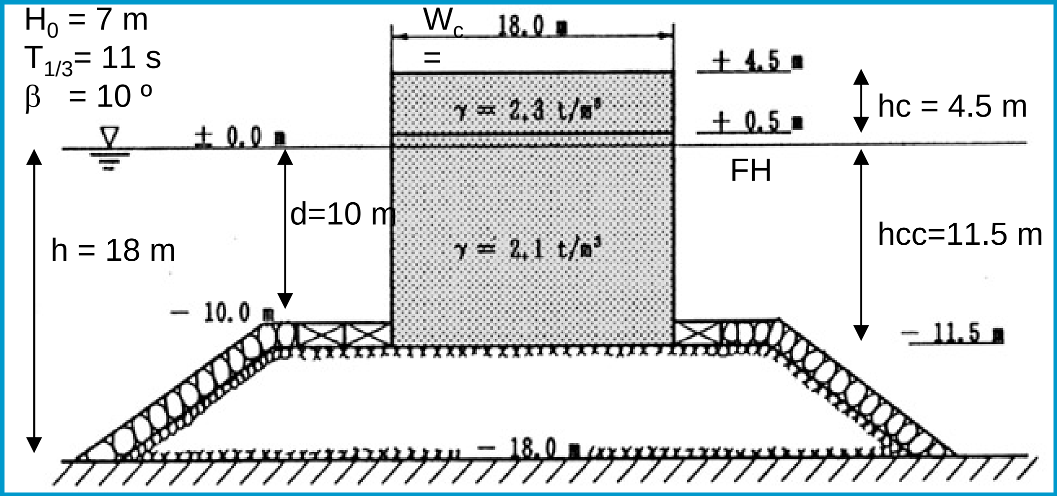
# Example

- “runup” $\eta$ = 17.2 m
- safety factors “just sufficient”

examples: H 7-15; Fslide; T(6) 10-15
H 7-15; Fslide; hcc(6) 10-15
H 7-15; Fslide; h(6) 15-20
H 7-15; Fslide; wc(6) 15-25
H 7-15; Foverturn; wc(6) 15-25



# Damage due to typhoon Togage (Oct 2004)

Susami Wakayama



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# Overflow over a caisson (1)

$$q = 0.2\sqrt{gH_s^3}\,\exp\left(\frac{-4.3F_b}{\gamma H_s}\right)$$

formula of Van der Meer and Franco

$F_b$ freeboard

$\gamma$ parapet shape factor

0.7 normal parapet

1.0 perforated caisson

1.15 is maximum value

# Overflow over a caisson (2)

TAW-report “waterkerende kunstwerken”
based on research at HR Wallingford

$q_{gem}$ = 5.013 $10^{-3}$ $k_w k_a g H_s T_z \exp(-20.12\ k_b\ F_b/(T_z \sqrt{(gH_s)}))$

$k_w$ wind effect surcharge

$k_a, k_b$ correction for oblique waves

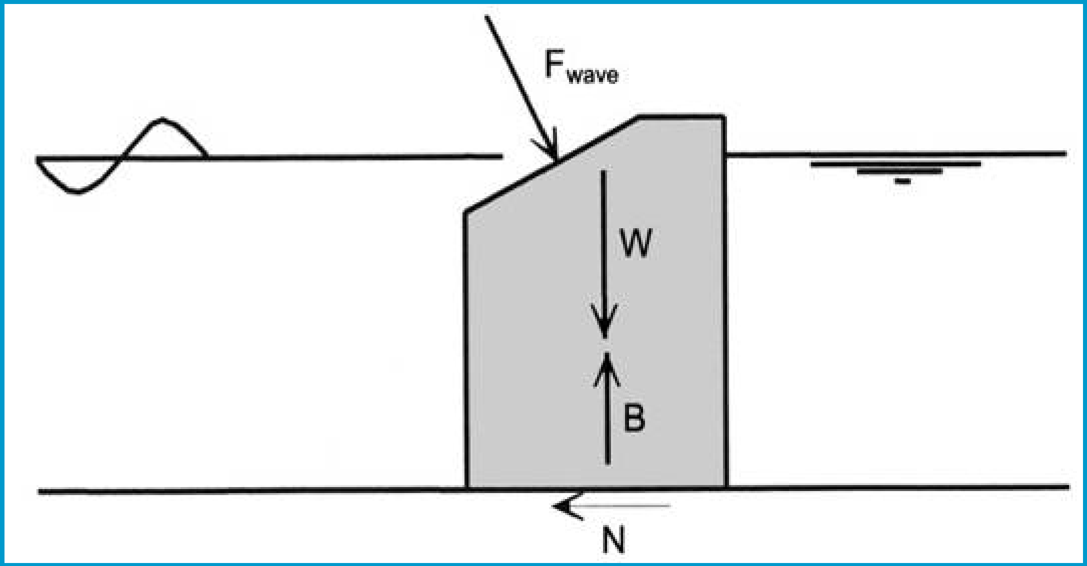
$F_b$ freeboard

example:
$H_s$ = 1.8 m; $T_z$ = 3 s; $V_{wind}$ = 15 m/s
Fb 0.25 - 2; q; Ftype(3)1-3

1= Van der Meer & Franco
2= Wallingford/TAW
3= Van der Waal, Delft Hydraulics

# Overflow over a vertical wall

# Hanstholm caisson



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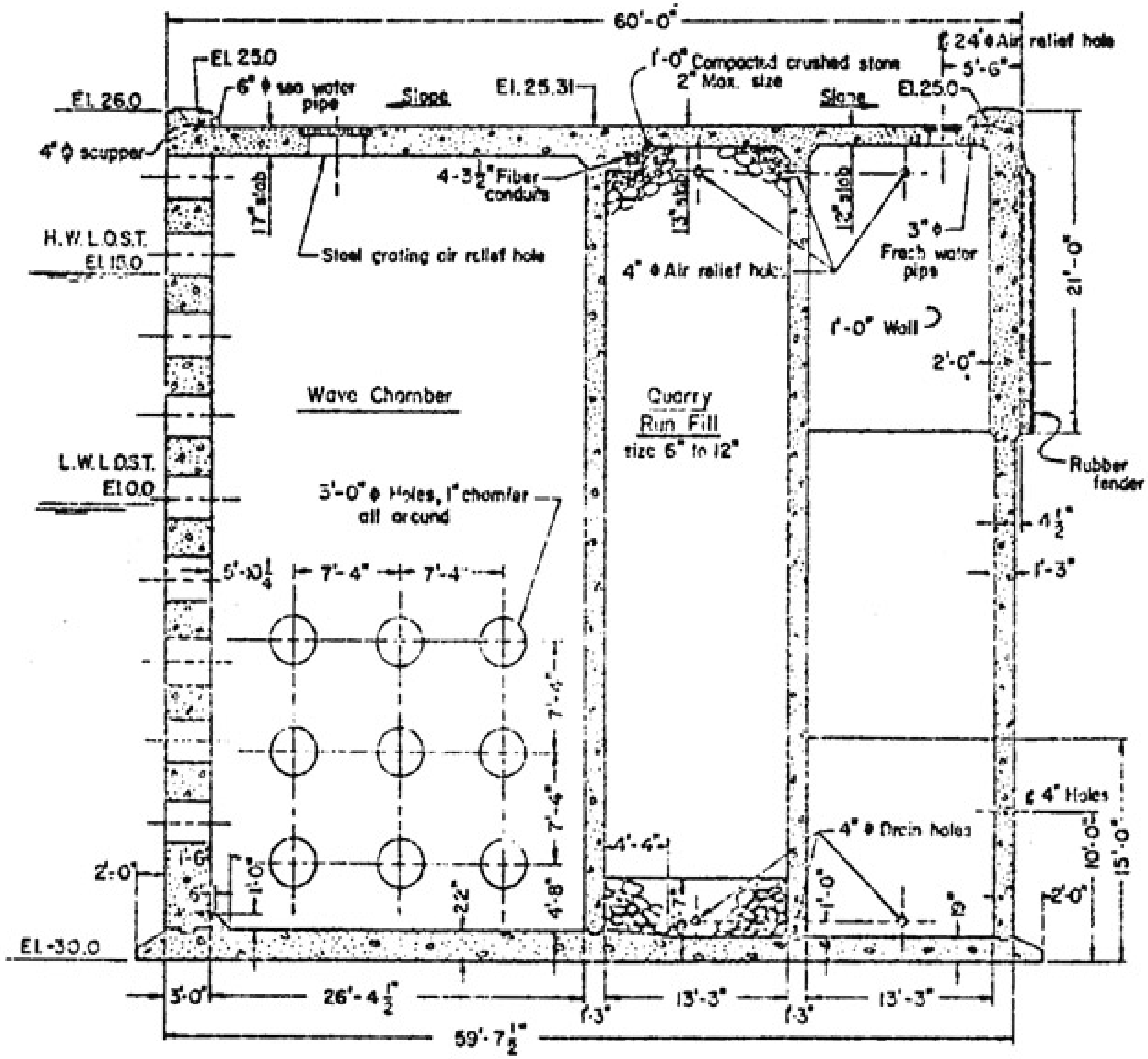
# Jarlan Caisson



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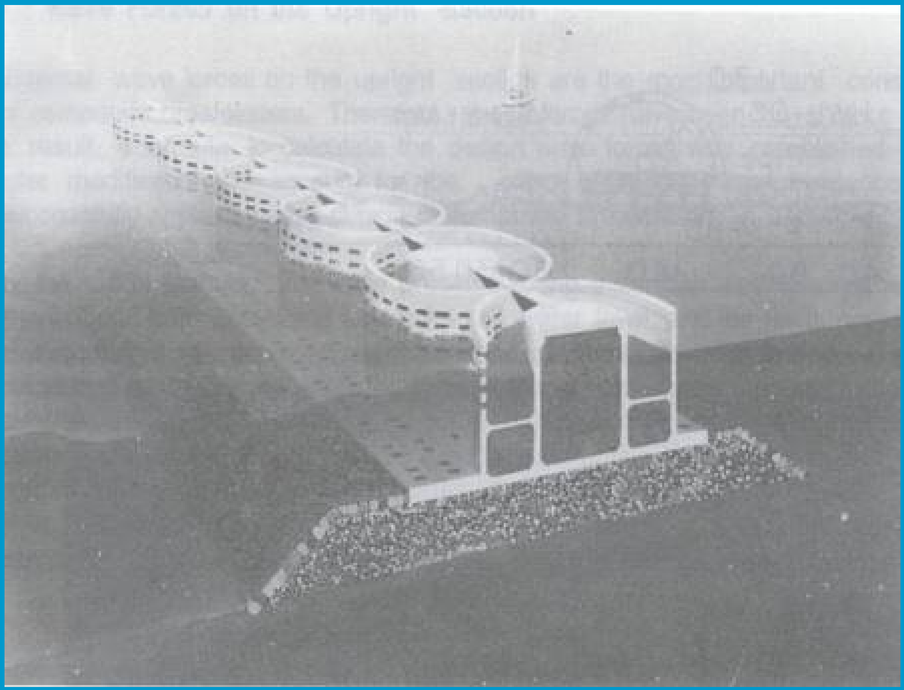
# Cylindrical breakwater, Nagashima





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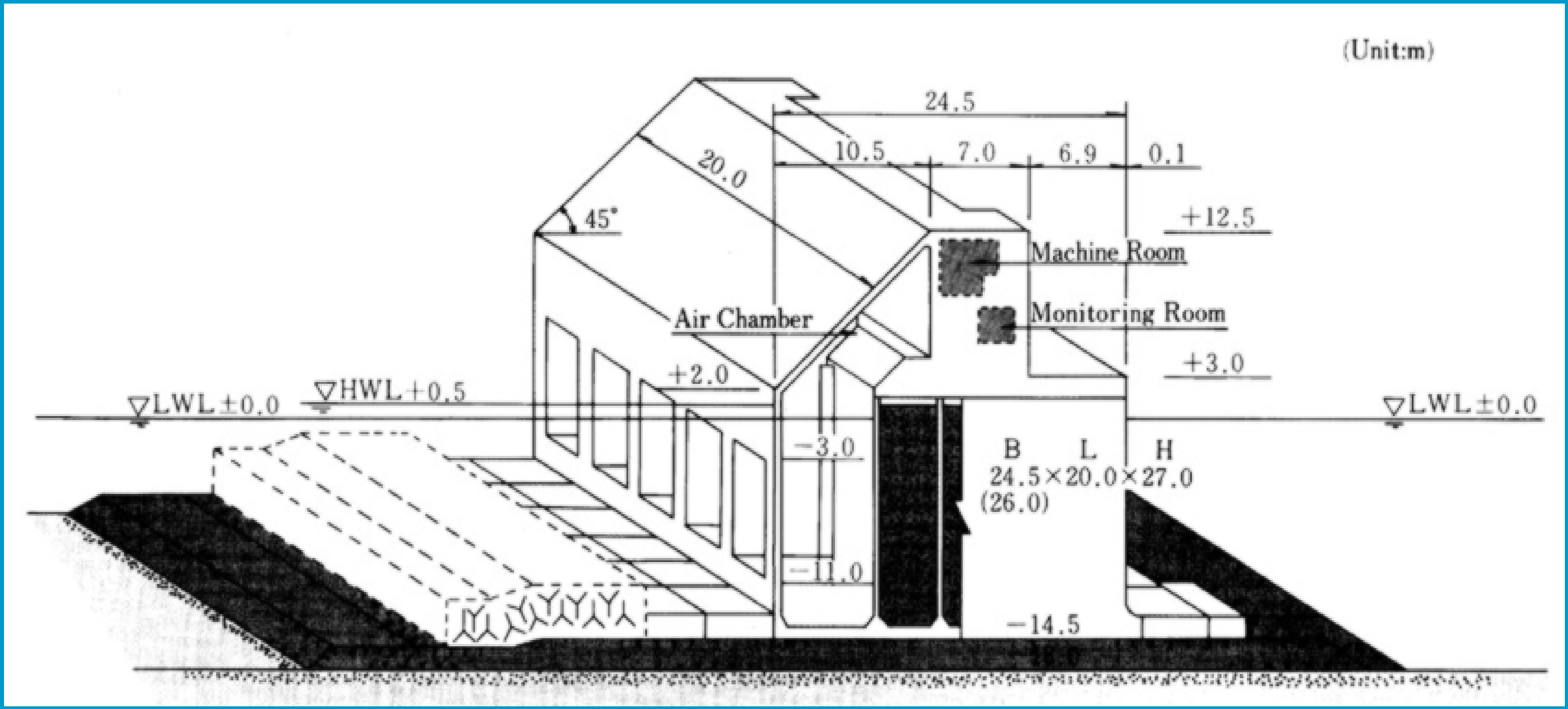
# breakwater with wave power generating system



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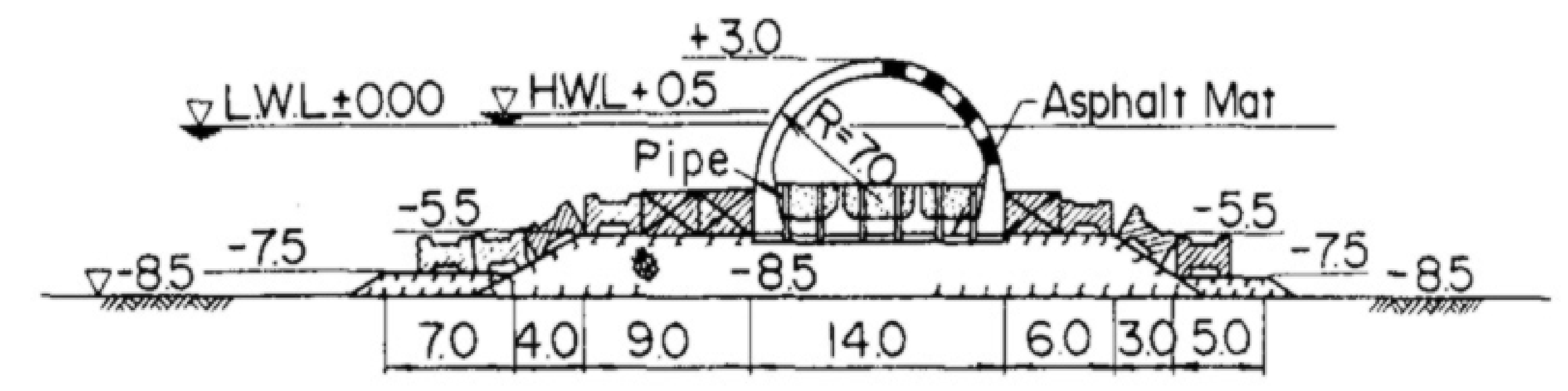
# semi-circular caisson
# (for extremely high breakers)



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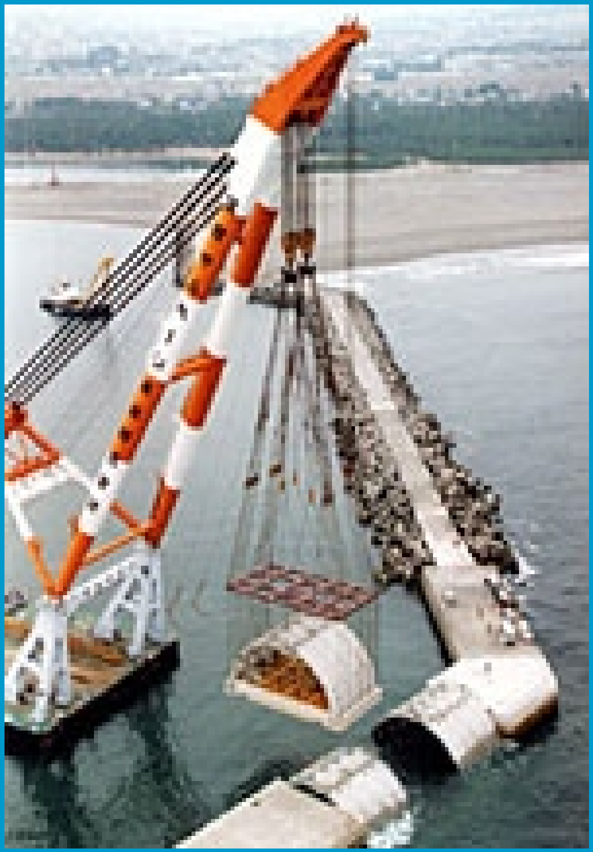
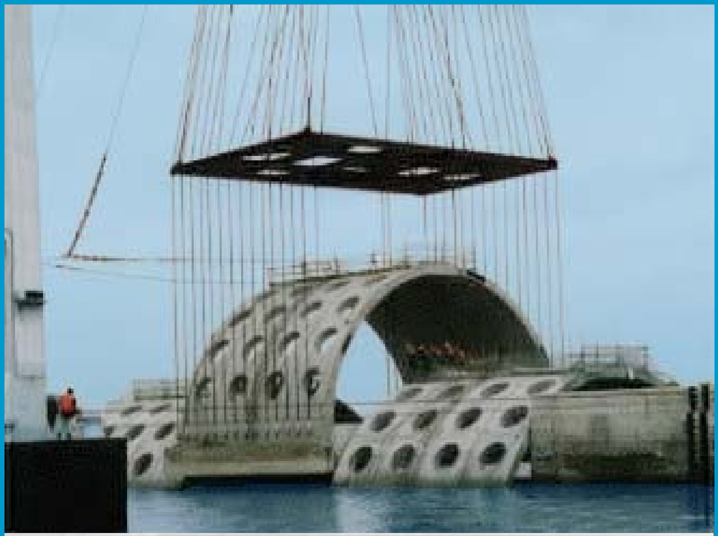
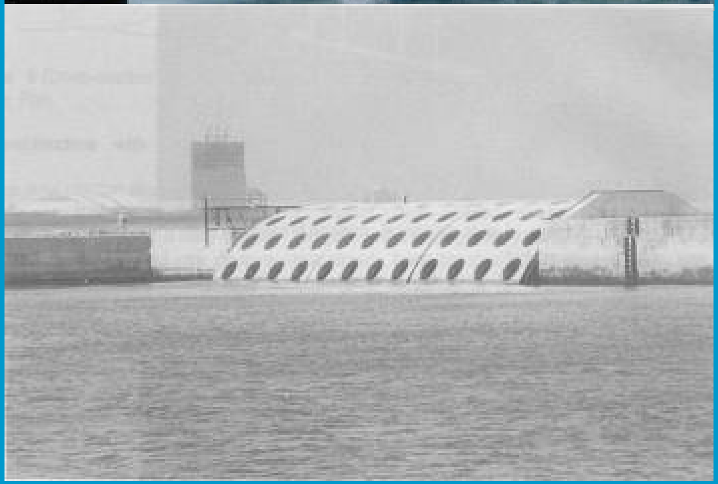
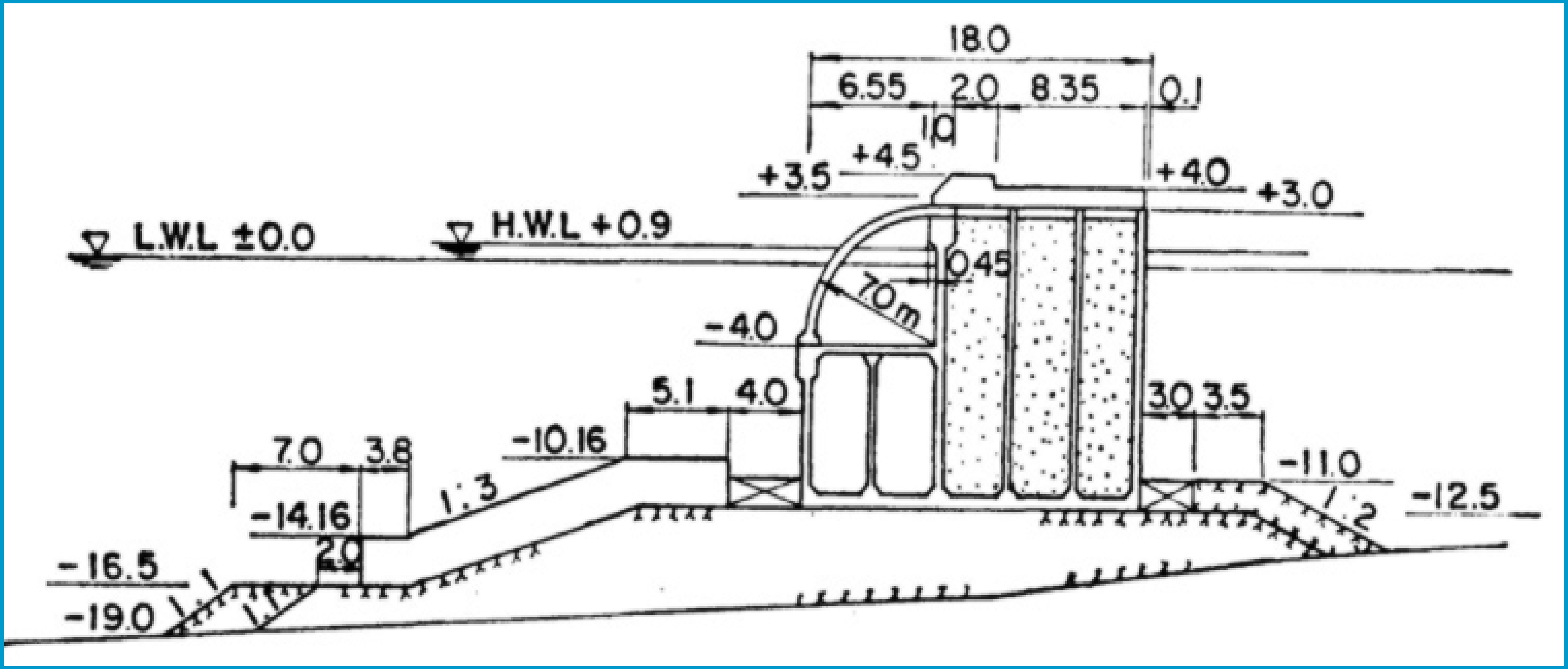
# The Miyazaki breakwater







# Curved slit breakwater
# Funakawa Port



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# Composite, curved breakwater



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# Honey comb wall breakwater



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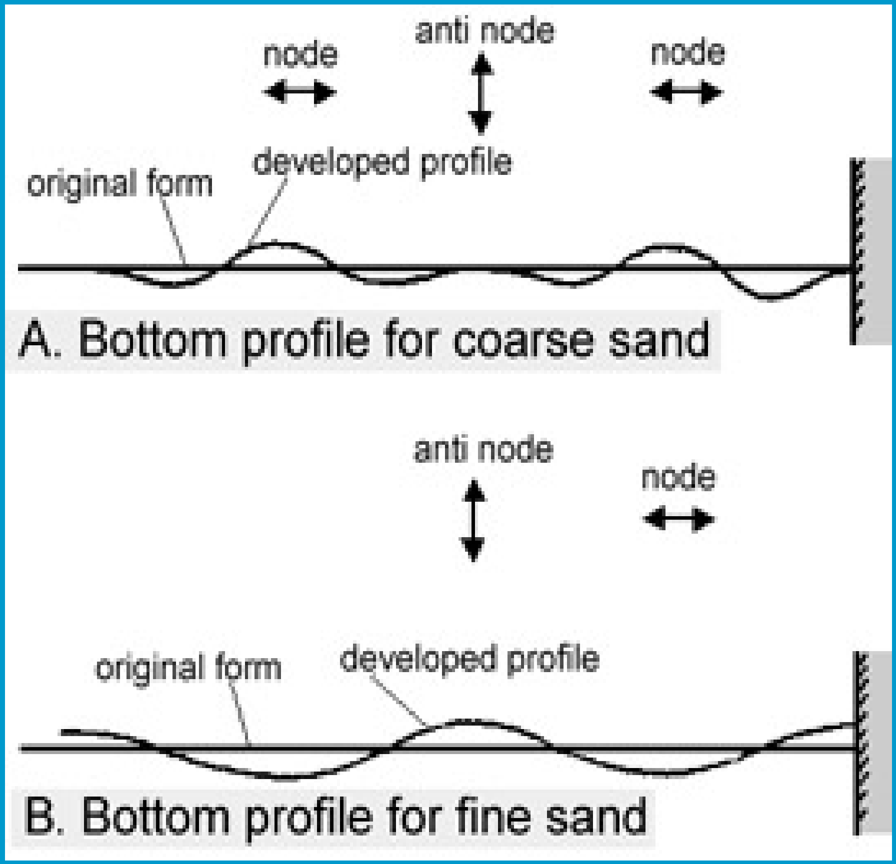
# erosion pattern depending on the grain size



# Do not forget the filter layers

**ct4310**

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